XVIII. *On the multiplication of images, and the colours which accompany them in some specimens of calcareous spar. By* David Brewster, *LL.D. F.R.S. Lond. and Edin. In a Letter addressed to the Right Hon. Sir* Joseph Banks, *Bart. G. C. B. P.R.S.*

Read June 8, 1815.

Dear Sir,

The multiplication of images exhibited in some specimens of Iceland spar, appears to have been first observed by Dr. John Robison of Edinburgh, who showed the phenomenon to Mr. Benjamin Martin.* Having procured several specimens that had a similar property, Mr. Martin examined them with care, and published an account of his observations in his Essay on Iceland Crystal. The experiments of Martin were repeated by Mr. Brougham, who concluded that the images were produced by fractures, parallel or nearly so to the sides of the rhomboid, and Malus has more recently endeavoured to explain the phenomena, by the laws of extraordinary reflexion within doubly refracting crystals.†

All these philosophers agree in ascribing the multiplication of images to internal reflections, and they equally concur in regarding the colours of the images as the same with those of thin plates, and as produced by fissures, or fractures within the crystal.

* See Brougham's "Further Experiments, &c. on Light." Phil. Trans. 1797.

† I am acquainted with Malus's observations only from a short account of them given by Dr. Young.

In this state of the subject, my attention was accidentally directed to it, in consequence of having received, from Sir GEORGE MACKENZIE, Bart., some very fine specimens of calcareous spar, which possessed the property of multiplying and colouring the images. I examined with attention the different planes in which the images were polarised; I found that small crystals detached from particular parts of the specimens, possessed the same properties, and I represented in figures the specimens which I employed, and the interrupting planes by which the colours were obviously produced. These results convinced me, that the interrupting plane was not a fissure or fracture; and I conjectured that the colours were analogous to those produced by the action of crystals upon polarised light.* By following out this conjecture, I have been led to the true cause of all the phenomena, and of other analogous facts; and have thus been enabled to communicate to any specimen of Iceland spar, the faculty of multiplying and colouring the images, in a manner so exactly similar to the real specimens, that no person can discern the least difference between the phenomena of the artificial, and those of the natural crystal. The results to which this explanation leads, will, I trust, be equally interesting to the mineralogist and to the natural philosopher.

SECT. I. *On the phenomena exhibited by particular specimens of Iceland spar.*

Let AEBFHDGC, (Pl. XV.) fig. 1. be a rhomboid of calcareous spar, and let the supposed fissure by which the coloured images are produced, be in the plane ABCD. When a pencil of

* Treatise on new Philosophical Instruments, &c. p. 339, and Pref. p. xii.

light is transmitted through the faces BCGE and AFHD, or through the faces BFHC and ADGE, the object from which it proceeds has the appearance represented in Fig. 2., consisting apparently of three images. The middle image A is white and is composed of two images A, *b* polarised in an opposite manner like the double image formed by common rhomboids of calcareous spar. The image B, which is highly and uniformly coloured, is polarised like A, and the image *a* is coloured in the same manner as B, and polarised in an opposite manner like the other image at *b*.

Let the rhomboid be now placed in such a position, that a horizontal pencil of light is incident upon the vertical face BCGE, and let the rhomboid be turned round a vertical axis, so that the pencil may be incident at various angles, the plane of incidence being always parallel to the horizon.

When the angle of incidence is about 10°, and the ray inclined towards EG, the two images B, *a* vanish, their angular distance being then about $3\frac{1}{4}°$, but at every other angle of incidence, these two images are visible. When the angle of incidence is gradually diminished, till it vanishes and then increases on the other side of the perpendicular, the reappearing images B, *a* separate from the middle image. The image B separates from it more rapidly, and increases in magnitude, in the same manner as when a pencil of light is incident obliquely *towards the refracting angle* of a prism, while the image *a* separates slowly from A, and contracts its dimensions, as when a pencil of light is incident obliquely *towards the base* of a prism. When the angle of incidence increases from the position where B and *a* vanish, these images approach to the middle image

A*b*; constantly varying their colours in such a manner, that the middle image A*b* has *a colour complementary* to that of the extreme images B and *a*.

If the angle of incidence is made to vary in a vertical plane, the extreme images separate from the middle image when the pencil is inclined to G*c*, but they approach it, and exhibit the complementary colours when the inclination of the pencil is towards BE. During these changes the colour of A is often complementary to that of *b*.

When the eye is placed in front of the face BCGE, so as to perceive the images reflected from the posterior surface AFHD, each of the images *a*, *b*, A, B is tripled in passing the plane ABCD, so that *nine* highly coloured images are distinctly visible.

In a very curious specimen of calcareous spar in the possession of Mr. Mylne, there are two supposed fissures as shown at *afhd* and *ebcg*, fig. 7. These planes are equidistant from the obtuse angles E, F, and each of them produces three images which are never coloured, except when the incident ray is very oblique, and the two extreme images near the middle one. In this case, the colour of the middle image is distinctly complementary to that of the extreme images. When the light passes through the faces AEGD, BFHC in such a manner, that the eye receives part of the pencil acted upon by the plane *e b c g*, and part of the pencil acted upon by the plane *a f h d* each of the three images appears double, and in consequence of a third plane $\varepsilon\beta\kappa\gamma$, one of the extreme images is sometimes tripled, so that the eye may see at once *seven* images independent of the numerous images

which are formed by reflections from the sides of the rhomboid.

All the specimens of interrupted calcareous spar which I have examined, present a very remarkable and beautiful phenomenon which has not hitherto been observed. Let AEBF, Fig. 3. be a section of the rhomboid shown in Fig. 7, and BA the interrupting plane; a ray RS incident in a direction nearly parallel to BA will be refracted in the direction ST, and passing through the plane BA at T, will emerge in the direction VX. Another ray *rs* incident on the adjacent face BF, and parallel to SR, will be refracted in the direction *s*T, and suffering reflection at *T* in the direction TV will also emerge in the line VX. If the face BF is covered, an eye placed at X will perceive across the middle image A*b*, Fig. 2. a series of beautiful fringes concave towards B, Fig. 3. and separating a bright from a dark space which is towards B. The predominant colour in these fringes is yellow: their direction is perpendicular to the line joining the images *a*, *B*, Fig. 2, and they increase in breadth towards E, Fig. 3. fading away in pink and green fringes. If the face BE is now covered, an eye at X will perceive a series of fringes complementary to the first set, and having a bright blue for their predominant colour. They have the same curvature and direction as the first set, and separate a bright from a dark space which is towards E, but they are far superior to them in distinctness and splendour of colouring. By covering only a part of EB, we can see at the same time both the sets of fringes, the yellow stripes of the first set joining the blue stripes of the second. This junction of the fringes forms a very interesting pheno-

menon, and is the only perfect example in which the complementary fringes are seen at the same instant.* In the specimen shown in Fig. 7, one of the interrupting planes gives remarkably minute fringes, while the other forms them of a larger size.†

SECT. II. *On the position and character of the interrupting plane.*

In every specimen of calcareous spar which possesses the property of multiplying and colouring the images, there is a plane ABCD, Fig. 1. stretching across the crystal. This plane, which I shall call the *interrupting stratum*, has not the most remote likeness to a fissure or fracture, but resembles rather a thin vein or film cohering to the two prisms between which it is interposed. The lines AB, CD which form the termination of the stratum, are distinctly marked on the natural faces of the crystal, and form straight lines perpendicular to the shorter diagonal FE; and the rhomboid is divided by the interrupting stratum into two equal prisms ABCDGE, ABCDHF, having the angles ABE, BAF each equal to 39°.

If the plane ABCD is a fissure or a stratum of air, as has been supposed, it is demonstrable that a ray of light incident at an angle of 37° upon AB will suffer total reflection, and therefore no light will be transmitted through the rhomboid. So far, however, from this being the case, there is actually no angle of incidence at which total reflection takes place at the second surface AB, and consequently there is no physical

* An imperfect example of this I have given in the Phil. Trans. 1814, p. 227. Plate VIII. fig. 3.

† In the specimens represented in Plate XI. fig. 8 and 11, of my Treatise on New Philosophical Instruments, the fringes are very large.

breach of continuity between the two prisms. If the adjacent surfaces of the prisms were perfectly smooth, and flat, like plates of parallel glass, and if they were pressed together by a great force, total reflection would thus be prevented, and the light would pass through the fissure at any obliquity. But if total reflection were prevented in this manner, the pencil of light would experience no peculiar action in passing through the compressed surfaces, and therefore neither a multiplication of images, nor a decomposition of the pencil into colours could take place.

With the view of corroborating this reasoning, I endeavoured to separate the two prisms by force, but I found this quite impracticable. The crystal actually broke at another place, so that the two prisms cohere with great force, though this is the direction of one of the cleavages of calcareous spar, and though the supposed fissure extends to the very surface of the four faces of the rhomboid.

But admitting the existence of a fissure under these circumstances, it is demonstrable that it could not produce the phenomena described in the preceding section. I have examined several real fissures in calcareous spar, and though the colours of thin plates were seen by reflection, yet those formed by transmitted light, could scarcely be rendered visible.

The appearance on the middle image of colours complementary to those on the extreme images, is an irrefragable proof that they are not the colours of thin plates, in which one of the complementary tints must necessarily suffer reflection.

In order to remove all doubt respecting the effects of a fissure, I ground off the angles EG, FH, Fig. 1. till the

crystal was bounded by the artificial faces *a f h d, e b c g*, and having polished these faces, I transmitted a pencil of light through the interrupting plane. In this case there was neither a multiplication of images, nor a production of colour, and the same result was obtained though I caused the pencil to fall upon the interrupting stratum at the same angle at which it was incident when the images were multiplied and coloured. Hence, it is obvious, that if the colours were produced by a fissure, they ought still to have appeared even when the fissure was bounded by parallel plates of spar.

In the specimen which is shown in Fig. 7, we are presented with several curious facts relative to the interrupting plane. This specimen is intersected by three interrupting strata *afhd*, *ebcg*, $\varepsilon\beta\kappa\gamma$, the two first being equidistant from AB, and all of them having the same position relative to the axis of the rhomboid. The thickness of the interrupting strata is distinctly seen at *af* and *eb*, and is nearly $\frac{1}{200}$ dth of an inch, bounded by two distinct parallel lines. The upper surface *af* of the stratum *afhd* is on a level with the general surface AEBF, but the upper surface *e b* of the other stratum forms an angle of 141° with the plane *e* E *b* and is smooth and well polished. The lower surface *dh* is partly level with the general surface, and partly inclined at an angle of 141° to the plane *d H h*, and the surface *gc* is parallel to the inclined surface *eb*. The two strata *afhd, ebcg* have therefore a crystallized structure, and as they effervesce with nitric acid, we are entitled to consider them as flat rhomboidal veins of calcareous spar.

The stratum *ebcg*, which is shown separately in Fig. 8, is divided into portions by four or five veins *mn*, *op*, some of

which, such as *r* and *s*, are not complete. When any of these minute veins, such as *mn*, is seen through the faces *e* E G *g*, *b* E G *c*, Fig. 9, it is quadrupled, and appears, as in the figure, composed of four veins *m* 1, *m* 2, *m* 3, *m* 4, and *n* 1, *n* 2, *n* 3, *n* 4 diverging from *m* and *n*. By gently inclining the rhomboid, all these veins are brilliantly coloured, and, what is very singular, the colours of the middle veins *m* 2, *m* 3, *n* 2, *n* 3, are always complementary to the colours of the extreme veins *m* 1, *m* 4, *n* 1, *n* 4, exhibiting a much greater variety of hues than is seen in any other position of the crystal.

In order to observe the connection between the stratum *eb* and the contiguous prisms, I cut off part of the prism *e* E *b* and laid bare the surface of the stratum towards E. I then removed the stratum itself till I came to the adjacent surface of the prism, and in both cases I found the particles of the prisms adhering firmly to the stratum, though they were at such a distance from it that light incident obliquely suffered reflection.

From these experiments, we may safely conclude, that the interrupting stratum is not a fissure or fracture;—that it is a crystallized vein of calcareous spar, cohering firmly to the adjacent mass;—and that the multiplication of images and the colours which accompany them, are produced only when this vein is interposed between two solid prisms.

SECT. III. *On the cause of the multiplication of the images.*

If a ray of light RS is incident upon a rhomboid EBFA, Fig. 4, interrupted by a stratum of air AB, it will be divided by refraction into two pencils S *a*, S *b*. These pencils will be again refracted at the second surface *m n* into the directions

ac, *bd*, and falling upon the second prism at *c*, *d*, each of them will be again divided into two pencils, viz. *ac* into the pencils *ce*, *cf*; and *bd* into the pencils *dh*, *dg*. The pencils *cf*, *dg* emerging parallel to each other, will form a double image like A*b*, Fig. 2, while the other two pencils *ce*, *dh* will be inclined to these, and will form the single images *a*, B. The images will therefore be multiplied exactly as in Fig. 2, and if we calculate their angular distance, we shall find it coincident with the experimental results. This multiplication of the images may perhaps be more easily comprehended by supposing A, B, Fig. 2. to be two images formed by the first prism ABE, Fig. 4; then as the second prism ABF has an equal refracting angle, but placed in an opposite direction, it will refract the image B to *b*, and the image A to *a*, thus forming a double image in the middle, and a single image on each side of it polarised in the manner described in Sect. I.

In the preceding reasoning it is assumed, that there is an interruption in the structure of the rhomboid by which a subdivision of the rays takes place within the crystal. We shall now enquire how such an effect can be produced without a fissure. If we divide a rhomboid into two prisms ABE, ABF, and fill up the interval AB with a cement of the same or of a different refractive power from that of the calcareous spar, the ray RS will emerge in four pencils *ce*, *cf*, *dg*, *dh*, just as when AB was a stratum of air, and in so far as the multiplication of images is concerned, this artificial rhomboid will exhibit the precise phenomena described in Sect. I.

Hence it follows, that the multiplication of images arises from a subdivision of the two pencils at the first surface

of the second prism, and that the great angular distance of the images, which takes place even when the prisms are connected by a cement in perfect contact with each, is occasioned by the action of the doubly refracting force near the second surface of the first prism.

As all the phenomena of the natural crystal may be imitated by an artificial one, there can be no doubt that such changes actually take place within the crystal. It is interesting, however, to ascertain the principles on which these changes depend; and we are fortunately able not only to do this, but to apply the principles to the explanation of other phenomena exhibited by doubly refracting crystals.

It may be shown by various experiments, that the division of a beam of light into two pencils by double refraction, does not take place till the light has penetrated the first surface of the crystal, and suffered the ordinary refraction, while at the second surface the extraordinary refraction takes place before the emergence of the ray. The interposition, therefore, of a film AB of the same refractive power as the crystal, though it prevents the ray from suffering any ordinary refraction, still allows the extraordinary refraction to take place just as if the prisms were completely separated. For the same reason, the extraordinary refraction again takes place at the first surface of the second prism, and the two pencils are divided into four, as represented in Fig. 2.

Since the prisms ABE, ABF, Fig. 4, or the rhomboids which they contain, have their homologous sides parallel, the pencils *Sa*, *Sb* ought not to be divided into two by the second prism according to the observations of HUYGENS and NEWTON.

This, however, is true only when the pencil is incident at an angle of between 12° and 14°, as described in Sect. I.,* and we have already seen that in this case the images are reduced to two. In every other position of the incident ray, the pencils are subdivided by the second prism.

The division of the pencil into two parts after it has penetrated the first surface, or before it has emerged from the second surface of calcareous spar, enables us to explain the curious fact observed by MALUS, relative to the light reflected from the interior surface of doubly refracting crystals. He discovered that the ray refracted ordinarily at the second surface was reflected at this surface in two pencils, one ordinary, and the other extraordinary; and that the ray refracted extraordinarily at the second surface, was also reflected in two pencils; so that there were four reflected rays, and only two emergent ones. These four rays returning to the first surface of the crystal, emerge in four parallel pencils, which form with this surface the same angle as the incident ray.

The cause of this singular fact will be understood from Fig. 5, where ABCD is a piece of calcareous spar, and mn, $\mu\nu$, the lines within the crystal at which the extraordinary refraction takes place. A ray of light RS will be divided into two pencils Sa, Sb, which will emerge in lines $a\,\alpha$, $b\,\beta$, parallel to RS. The reflected portions bd, ac will be subdivided at c and d, just as if they had been incident in the directions $\delta\,b$, $\varkappa\,a$, and will form four pencils ce, cf, dh, dg, which is the phenomenon observed by MALUS. In order to show experimentally that the rays $a\,\alpha$, $b\,\beta$ are subdivided at c and d, when received upon the rhomboid in the directions $\delta\,b$, $\varkappa\,a$, cement

* I shall have occasion to consider this law in a subsequent Paper. I have stated the angle at between 12° and 14° as the pencil dh Fig. 4. vanishes at a less angle than ce.

a plate of glass GH, Fig. 6. upon the second surface CD, by means of a transparent cement EF. The rays S*a*, S*b* have now emerged completely from the calcareous spar, and being reflected from the glass plate GH, they again enter the crystal, and are subdivided as formerly at the line *mn*, into the four pencils *ce*, *cf*, *dg*, *dh*.*

In a specimen of calcareous spar examined by Mr. MARTIN, *twelve* images were seen, arranged in three rows. The middle row, consisting of *six*, was produced by two interrupting planes situated in the manner shown in Fig. 7, while the other two rows were formed by reflection from the sides of the rhomboid. Mr. BROUGHAM examined a specimen which afforded *six* images in some positions, besides other two, which, as this able writer justly remarks, were reflected from the sides of the specimen.

SECT. IV. *On the cause of the colours with which the images are affected.*

As there are some specimens of calcareous spar in which the multiplication of the images is not accompanied with the production of colours, the one phenomenon is not necessarily connected with the other, the multiplication of the images depending merely on the interruption in the regular structure of the mineral, and the colours upon the thickness and crystalline nature of the vein by which that interruption is produced.

We have already seen that the double image A*b* (Fig. 2.) is in general white, while *a*, and B, are affected with the same prismatic colour, and that when A*b* is coloured at particular angles of incidence, its colour is always complementary to

* MALUS believed that the fact of the subdivision of the reflected pencils was general; but there is obviously a particular angle of reflection at which four pencils are not formed.

that of *a* and B. These colours are therefore produced by the transmission of polarised light through the crystallized film AB, Fig. 4. The light is first polarised by the prism ABE: it is then separated into its complementary colours by the crystallized film AB, and this compound beam is analyzed by the second prism ABF. This arrangement, indeed, is the very same as that which I have described in a former paper,* as necessary for the exhibition of the complementary colours, the light being polarised by double refraction instead of by reflection, and being analyzed by a prism of calcareous spar, instead of a plate of agate.

In order to put this explanation to the test of direct experiment, I cut a rhomboid into two prisms ABE, ABF, Fig. 4, having equal refracting angles; and I interposed a thin plate of sulphate of lime between the two prisms. When the light was incident on the first surface EB at an angle of between 12° and 14°, so that the two images *a*, B, had vanished, I shifted the sulphate of lime till it ceased to depolarise the light, or restore the vanished images *a* and B. I then cemented it in this position to the two prisms, and thus obtained an artificial rhomboid, which imitated with the utmost exactness all the phenomena of the natural one. The extreme images *a*, B, became coloured, while the double image A *b* remained white, and the colours varied by varying the inclination of the plate to the incident rays. The images *a* and B approached to, and receded from, the middle image as in the natural crystal, and at particular incidences the middle image exhibited colours complementary to those of the extreme images, and of the very same kind with those in the natural rhomboid.

* Phil. Trans. for 1814, p. 210.

When the position of the sulphate of lime is changed, the depolarisation is increased, and the double image A*b* is no longer white, but always displays the colours complementary to those of *a* and B. In particular positions of the sulphate, the middle images become white at an oblique incidence.

In the specimen of calcareous spar represented in Fig. 7, the colours are by no means brilliant, and they appear only when the incident ray falls obliquely upon the rhomboid, with an inclination towards the base of the first prism. The reason of this will appear from Fig. 4. When the ray is incident obliquely towards the base of the first prism, as *r*S, it is refracted in the direction S *m*, and passes through the interrupting stratum AB nearly at its least thickness; whereas when it is incident obliquely in the direction ϱ S, it is refracted into the line S*n*, and passes obliquely through the stratum at a thickness too great to produce the complementary colours. We are presented therefore with a method of determining rudely, the comparative thickness of the strata by which the colours are produced. In two very fine specimens, the colours are exhibited at almost every inclination, and they vanish when the inclination is near its maximum, and when the ray passes obliquely through the stratum.

Hence it follows, that the colours are produced by the transmission of polarised light through a crystallized vein, and that the phenomena change their character with the thickness of the vein.

We have already seen that the images may be multiplied without being coloured, but they cannot be coloured without being multiplied, as the separation of the oppositely polarised pencils is necessary to the production of the colours. This is

proved by grinding off the angles EG, FH. Fig. 1, so as to make the interrupting stratum parallel to the two faces of the crystal. There is in this case no multiplication of images, and no production of colour.

The complementary fringes described in Sect. I. are likewise produced by the transmission of polarised light through the interrupting stratum. When the ray RS, Fig. 3, is incident at various angles upon EB from the position *r* S, Fig. 4, to the position RS, Fig. 3, the refracted ray ST passes through the stratum AB at various thicknesses, and it therefore exhibits different colours corresponding to these thicknesses. When the ray has the position RS, the thickness of the film becomes so great, that the colours cease to be developed, and this limit of the production of colour is marked by parallel fringes gradually diminishing in breadth towards that limit. In like manner the ray *r s* being refracted in the direction *s* T, and falling upon AB at T, will pass through it at the same thickness as the ray RS does, and being reflected from the posterior surface of the stratum, will move in the direction TV, and emerge in the line XV. Fringes of the same character, but complementary to the former, will thus be produced by reflection, and from the equality of the angles STB, *s* TB and ATV, the fringes formed by transmission will be seen in the same direction XV as those seen by reflection. The reason is therefore manifest why the one set of fringes is seen by covering the face EB, and the other set by covering the face BF, and why both sets are visible when only part of EB is covered.

In order to show that these fringes are produced by the action of the crystallized film upon polarised light, I examined the phenomena in the following manner. As the double

image A *b*, Fig. 2, across which the fringes are visible, is formed by two equal and oppositely polarised pencils, it is necessary to the production of the fringes, that one of these pencils be either extinguished, or greatly diminished in its intensity. Now, if we cover BF, and examine with a prism of calcareous spar the pencil VX formed by the rays RS, we shall actually find that one of the images, *b* for example, Fig. 2, is very much fainter than the other, and therefore the fringes must be formed of the polarised light of A, being in this case very faint, owing to the admixture of the remaining light of *b*. If, on the contrary we cover EB, and examine the pencil XV formed by the rays *rs*, we shall find that the image *b*, Fig. 2, is almost wholly extinguished, and consequently the fringes formed by the polarised light of A are remarkably distinct, suffering no diminution of lustre from the admixture of oppositely polarised rays.

If the rays RS, *rs*, (Fig. 3.) are now polarised before their incidence upon the rhomboid, the fringes formed by *rs*, do not experience any change, in consequence of their being produced by unmixed polarised light; but the fringes formed by RS suffer a particular modification. When the plane of incidence EBFA forms an angle of 45° with the plane of polarisation, the fringes are extremely distinct and beautiful, and the same thing happens when the rhomboid is turned round 180°. In positions at right angles to these, no fringes whatever are visible. In the first of these positions, the pencil is not divided into two oppositely polarised pencils, whereas in the other position, it is divided into two oppositely polarised pencils of equal intensity.

If instead of polarising the incident rays RS, *rs*, we examine

the resulting pencil VX with a prism of calcareous spar, we shall find certain positions of the prism in which the fringes are invisible. In some positions they are finely displayed across the first image, and are not visible across the second; while in other positions the fringes across the first image vanish, and appear distinctly across the second. All these phenomena arise from the alternate evanescence of the images, which causes the fringes to be seen across the remaining image formed by light polarised in one plane.

The explanation which has now been given of the iridescent phenomena of calcareous spar, enables us to account for the origin of the colours peculiar to the agate, which I have described in a former Paper.* These colours always appear in veined agate, and are, undoubtedly, produced by the interposition of a vein between two equiangular prisms.

Sect. V. *Description of new instruments for exhibiting complementary colours.*

A simple instrument for exhibiting the opposite or complementary colours has long been a desideratum in the arts, as well as in the sciences. To painters, and to artists of almost every description, it is of very extensive use, while in many optical inquiries its advantages cannot be sufficiently appreciated.

The method of showing these colours which I have pointed out in a former Paper, consists in the separation of polarised light into two pencils, by the action of a crystallized plate, and in the subsequent analysis of the pencil, by a doubly refracting crystal. The simplest way of fitting up an instru-

* See Philosophical Transactions, 1813, p. 102, 103, and 1814. p. 197, 199.

ment upon this principle is shown in Fig. 10, where ABCD is a tube one or two inches long, S a piece of black glass forming an angle of 33° with the axis of the tube; *n* a convex eye glass placed next the eye; *o* an aperture of a circular or any other form in the focus of the lens *o; m* a flat piece of topaz or rock crystal* not much larger in diameter than the pupil of the eye, and cut in the proper direction from the crystal; BD a prism of nearly the same diameter formed out of rock crystal in the manner long ago described by M. Rochon,† so as to produce the greatest separation of the images, or what is still simpler, a prism of calcareous spar having the refraction and dispersion as much as possible corrected by an opposite prism of balsam of Tolu or indurated Canada balsam. When the instrument is thus fitted up, the rays RS, polarised by reflection from the glass S, are arranged into their complementary colours by the crystallized plate *m*, and are afterwards separated into two distinct pencils by the double refraction of the prism BD. An eye, therefore, placed at *n*, will see two distinct images of the aperture *o*, and the colour of the one image will be complementary to that of the other. These images will exhibit alternate variations of colour by turning round either the tube, or the polarising plane S. If

* A thin film of sulphate of lime is much better than any other mineral, as it requires no trouble to prepare it. Topaz is preferable to rock crystal, as the latter very often gives false tints, from a want of uniformity of structure. Mr. Sanderson, an ingenious lapidary in Edinburgh, has cut about twelve plates of rock crystal parallel to the axis of the pyramid, and observed, that all of them were filled with veins and imperfections radiating from the axis. In a large pyramid about 2½ inches in diameter, these radiations are arranged in the form of a cross, forming angles of 60° and 120°, and they terminate on the faces of the pyramid.

† *Journal de Physique*, 1801. *Mémoire sur le Micrometre de Cristal de Roche.* Paris, 1807.

the two images overlap, the parts that overlap will be white, in consequence of the combination of the two opposite colours. The object of using the lens *n*, is to shorten the tube, but if we remove the eye glass, the aperture *o*, may be made of any size, and placed at any distance from the eye.

I have been induced to give this particular account of the preceding instrument, as another instrument upon the same principle, but of a most unphilosophical construction, has recently been exhibited in Edinburgh as a new invention, without any mention having been made either of M. ARAGO or myself, who separately discovered the property of polarised light on which it depends, or of M. ROCHON who invented the eye-piece of the instrument. It consists of a tube from twelve to twenty inches in length for the purpose of producing a sufficient separation of the images, and a large object glass of rock crystal is placed at the very end of the tube, although a small piece $\frac{1}{6}$th of the size would have answered much better, and admitted of a larger aperture if placed near the eye. In order to polarise the light, the operator carries a large square plate of japanned metal, and places it as near the polarising angle as he can. The instrument is then directed to this plate, and exhibits two overlapping images affected with the complementary colours.

The investigation in the preceding pages, furnishes us with a principle for constructing a new *antichromatic instrument*, far superior to any of the preceding, and so very simple, that any person can make it for himself. It is represented in Fig. 11, where MNOP is a tube about two inches long attached to a ball and socket. The end MO of the tube carries an aperture of any form, and the ball CD contains two

prisms of calcareous spar separated by a film of sulphate of lime so placed that each pair of the four images is tinged with the complementary colours as described in Sect. IV. A lens L is cemented either upon the anterior or posterior surface of the compound prism, or may be kept separate from the prism at L, but whatever be its position, it must always enable the eye at E to see the aperture with perfect distinctness, and the focal length of the lens must be so adapted to the magnitude of the aperture, that the images of it can be sufficiently separated by the universal motion of the ball CD. The interior of the tube being covered with a black pigment, the instrument is ready for use. If we direct it to the sky, or to any luminons object, four brilliantly coloured images of the aperture will be distinctly seen, the colour of the two middle images being complementary to that of the two extreme images. By moving the ball in the socket, the colours will constantly change, and the images will sometimes over lap, and sometimes separate, exhibiting the finest variety of hues, and pleasing the eye by their combinations, and by the soft harmony of their contrasts.*

In the instrument where it is necessary to polarise the light by black glass, or japanned metal, there is no less than $\frac{12}{13}$ths of the incident pencil lost by reflection, while in the preceding instrument the light lost by transmission is very small. From this cause, the brightness of the colours is incomparably greater, and they may even be distinctly seen in candle light, by directing the aperture to a piece of white paper held near the candle.

* The phenomena will admit of many beautiful variations, by using several films of sulphate of lime, having their axes variously inclined to one another.

I shall now conclude this letter with the description of another instrument which I have found of great advantage in carrying on very delicate experiments on the polarisation of light. In comparing the quantities of light polarised in the plane of reflection by different metals, we derive very little aid from examining the partial evanescence of one of the images. The intensity of the complementary colours is a much more delicate measure of the portion that has received this character. The method of doing this is shown in Fig. 12, where ABCD is a tube about eight or nine inches long supported upon a stand. An equal and unbroken plate of *sulphate of lime* which gives an uniform tint in every part of its surface, is cemented with Canada balsam between two plates of parallel glass, and is placed at the end AB of the tube exposing two circular apertures *m*, *n*, to the incident rays. At the other end of the tube is a piece of black glass *op*, inclined at an angle of 33° to the axis of the tube, and having a motion of rotation round that axis. When polarised light is transmitted through the apertures *m*, *n*, and reflected from the surface *op* to the eye, these apertures will appear equally coloured in every position of *op*, the colour in one quadrant of its circular motion being complementary to that in the adjacent quadrants. If we now wish to compare the quantity of polarised light in a pencil reflected at an angle of 80° from *silver*, with the quantity polarised at the same angle by *steel*, we have only to transmit the one pencil through *m*, and the other through *n*, and the intensity of the colours will show which of the two contains the greatest quantity of polarised light. Or if we diminish the inclination of the steel surface

till the colours of the two apertures are equally intense, we obtain the angles of incidence at which *steel* and *silver* polarise equal quantities of light in the plane of reflection. By using two plates of black glass having a variable inclination to the axis of the tube, we may allow the light to fall at equal angles upon the two metals, and thus ascertain the different inclinations of the plates of glass at which the two apertures exhibit the same intensity of colour.

I have the honour to be, &c.

DAVID BREWSTER.

Edinburgh, May 1, 1815.

To the Right Hon. Sir JOSEPH BANKS, Bart. G. C. B. P. R. S. *&c. &c. &c.*

Fig. 1.

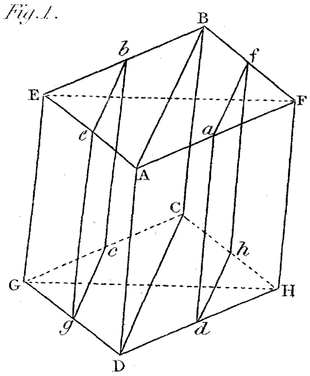

Fig. 3.

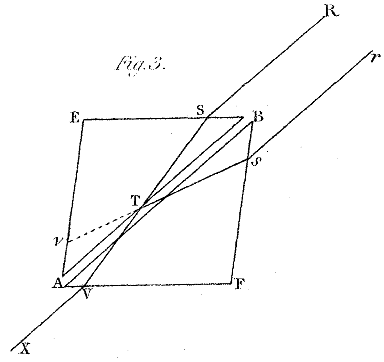

Fig. 4.

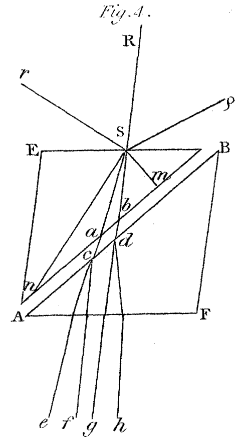

Fig. 2.

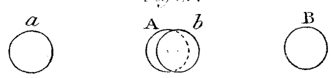

Fig. 5.

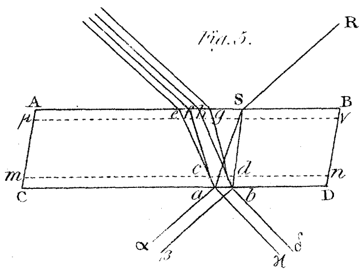

Fig. 6.

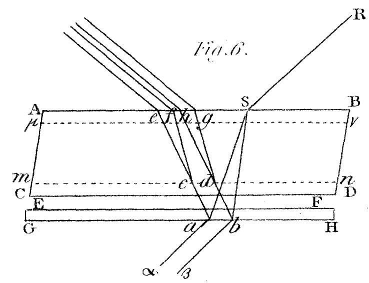

Fig. 7.

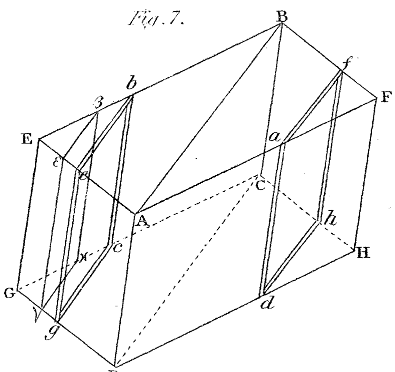

Fig. 8.

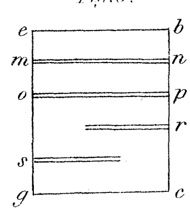

Fig. 9.

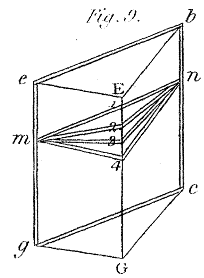

Fig. 10.

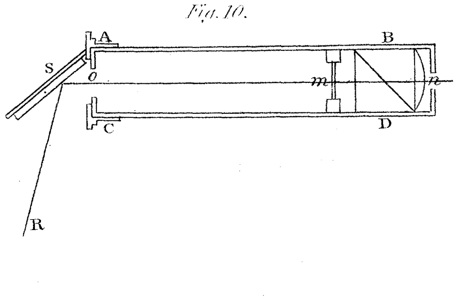

Fig. 11.

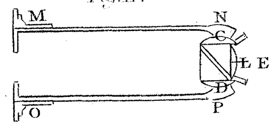

Fig. 12.